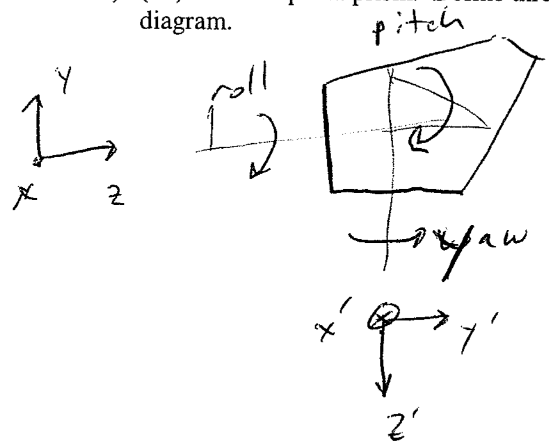
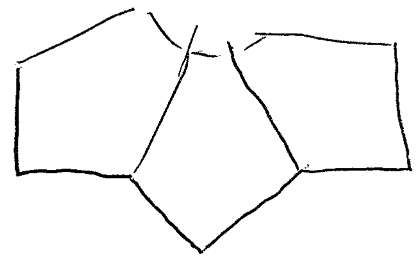
Solution

Optical Engineering 421/521 – Fall 2008
Midterm 1 Closed book, closed notes, **No calculators!** 50 minutes.

1.) (10) Sketch a penta prism. Define three axes and write the mirror matrix for this prism. Draw its tunnel diagram.





tunnel diagram

$$M = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & -1 \\ 0 & 1 & 0 \end{bmatrix}$$

2.) (5) For the prism above, describe what happens if the prism is rotated by a small angle about each of the three axes. (define roll, pitch and yaw on your sketch above)

θ_x pitch, no change

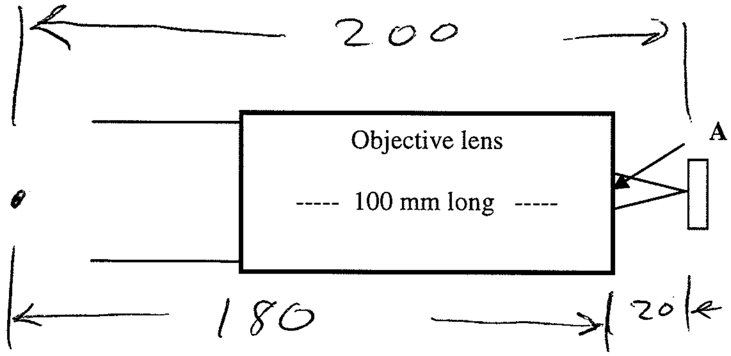
θ_z roll, line of sight rotates about z $= \theta_z$

θ_y yaw " " $= \theta_y$

+ image rotation $= \theta_y$

3.) (5) For the following case with an objective lens making an image of a distant object, determine the position of the nodal point and show it on the drawing. Show the position of the nodal point relative to point A:

50 mm aperture
200 mm EFL
20 mm BFD
5° FOV



4.) (5) What happens to the image if the lens above is tilted about point A by 1 mrad.

1 mrad about A causes nodal point translation

$= 180\text{ mm} \times 1\text{ mrad} = 180\,\mu\text{m}$

Image shifts by 180 μm

5.) (5) A 25 mm diameter lens has a spherical surface with requirements of R = 250 +/- 1 mm. Calculate the tolerance in terms of the sag of the surface. Is this tight?

$$S = \frac{r^2}{2R}$$

$$\Delta S = -\frac{r^2}{2R^2}\Delta R = -\frac{D^2}{8R^2}\Delta R \qquad (D = 2r)$$

$$= \frac{25^2}{8(250)^2}\cdot 1 = \frac{1}{800} = \cancel{12.5\,\mu m}$$

this is tight. 1.25 μm

6.) Consider an imaging system with an f/10 working focal ratio, operating at 0.5 μm wavelength. If the focal plane is shifted from the ideal position by 0.1 mm:

A) (5) determine the approximate wavefront error

$0.1\,mm = 2\lambda F_n^2$ gives $\lambda/4$ focus   Rule of thumb

or, from 5) $\Delta S = \frac{1}{8}\left(\frac{D}{R}\right)^2 \Delta R = \frac{1}{8F_n^2}\Delta R = \frac{1}{800} \cdot 100\,\mu m = \frac{1}{8}\,\mu m$

$= \lambda/4$

B) (5) determine the approximate Strehl ratio, assuming no other errors

SR for $\lambda/4$ focus is 80%   Rule of thumb

or $SR \doteq 1 - \sigma^2$ $\lambda/4$ P-V $\doteq$ $\lambda/16$ rms $\cong \frac{6}{16}$ radians

$\left(\frac{6}{16}\right)^2 = \frac{36}{256} = \frac{9}{64} \simeq 14\%$ $SR \cong 86\%$

7.) (5) A polished optic may have a scratch/dig specification of 20/10. Explain briefly what this means. Is 20/10 tight?

20 = scratch number, based on visibility of largest scratch

10 = dig number = largest dig ÷ 10 (100 μm)

Yes, this is very tight

8.) (5) What is the deviation from a 25 mm diameter f/10 BK7 lens that has 25 μm ETD?

Wedge angle = $\frac{ETD}{D} = \alpha$

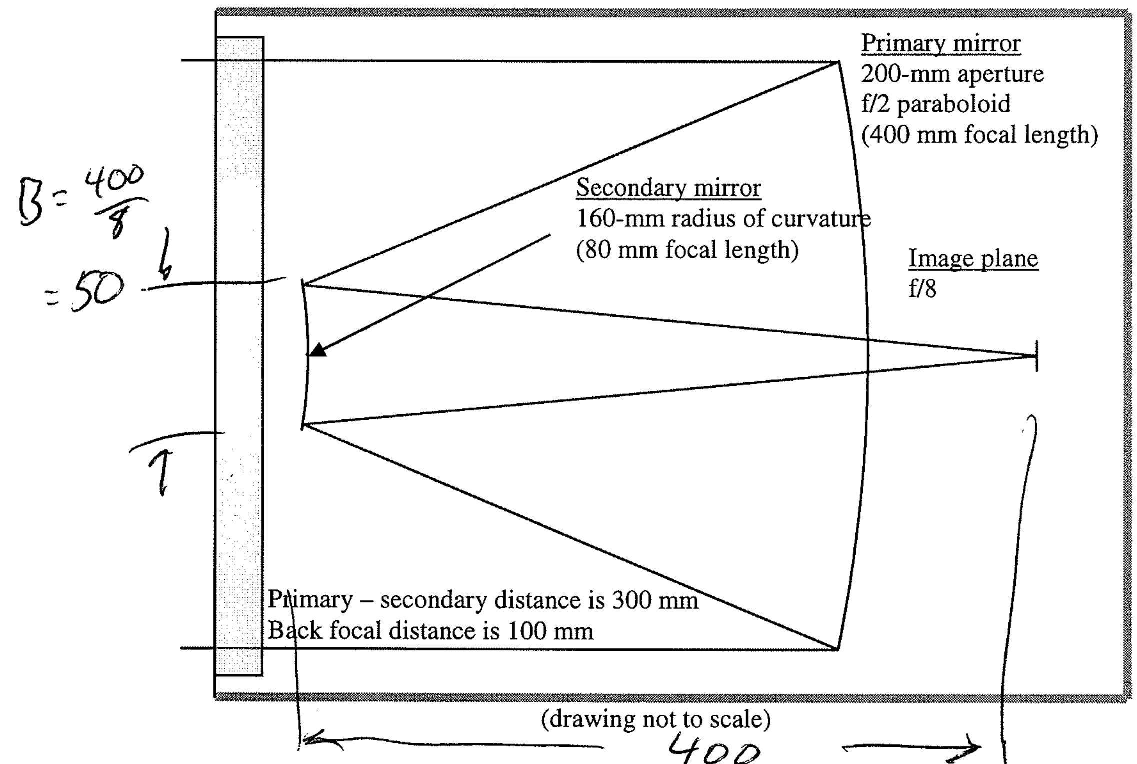
deviation $= (n-1)\alpha$

D 

$= (n-1)\frac{ETD}{D}$

$\cong 0.5 \frac{.25\,\mu m}{25\,mm} = 0.5\,mrad$

9.) (20) Consider the following Cassegrain optical telescope

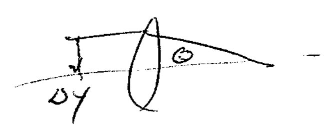


(drawing not to scale)

Find the effect of each mirror's rotation and lateral translation on system line-of-sight. Report the image motion due to the mirror motion as given below.

Mirror	Mirror motion	Resulting image shift
Primary Mirror 400 mm focal length	40 µm lateral motion	160 µm
	0.1 mrad tilt	320 µm
Secondary Mirror 80 mm focal length	8 µm lateral motion	40 µm
	0.1mrad tilt	80 µm

$$\varepsilon_i = F_n \cdot B_i \cdot \theta_i$$



Primary $F_n \cdot B_i = 8 \cdot 200 = 1600\ mm$

40 µm lateral tilt, $\theta = \frac{\Delta y}{f} = \frac{40\mu m}{400 mm} = 0.1\ mrad$

$\times 1600 = 160\mu m$

$\Delta\theta_i = 2\Delta\theta_p$ 0.1 mrad tilt $\Delta\theta = 2(0.1) = 0.2\ mrad$

$\times 1600 = 320\mu m$

SM: $F_n \cdot B_i = 8 \cdot 50 = 400\ mm$

Δy $\theta_2 = \frac{8\mu m}{80\ mm} = \frac{\Delta y}{f} = 0.1\ mrad$ $\quad \varepsilon = \theta \cdot 400 = 40\mu m$

$\Delta\theta$ $\theta_2 = 2 \cdot \Delta\theta_s = 0.2\ mrad$ $\quad \varepsilon = \theta_2 \cdot 400 = 80\mu m$

10.) (10) Consider the same system above. Assume the secondary mirrors is diamond turned so that it has surface ripple of 0.033 µm rms (1/30 µm rms) with spatial frequency 12.5 cycles/mm (80 µm pitch). The diffraction effect will cause each object point to have a ghost ring around it. For an operational wavelength of 2 µm

a) calculate the approximate rms wavefront due to the diamond turning rings

$$\Delta W = 2\Delta s = \frac{1}{15}\,\mu m\ rms \times \frac{1\ wave}{2\,\mu m} = \frac{1}{30}\ wave\ rms$$

b) from a), estimate the fraction of the light from a point source that would be scattered into this ring

$$\sigma = 2\pi \Delta W_{rms} \cong 6 \cdot \frac{1}{30} = \frac{1}{5}\ rad\ rms$$

$$Scatter = \sigma^2 = \frac{1}{25} = 4\%$$

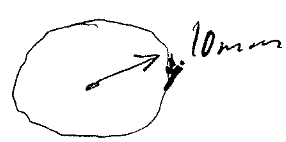
c) calculate the diffraction angle from the secondary mirror

$$diffraction\ angle = \frac{\lambda}{\Lambda} = \frac{2\,\mu m}{80\,\mu m} = \frac{1}{40} = 2.5\ mrad$$

Λ = spatial period = 80 µm

d) from c) calculate the radius of the ghost ring in the focal plane.

$$\theta_2 = 2.5\ mrad$$



$$\varepsilon = D_i F_n \cdot \theta_2$$

$$= 400\ mm \cdot 2.5\ mrad = \cancel{[illegible]}$$

$$= 10\ mm$$

11.) (20) Sketch a 3-view orthographic projection of the following part, include dimensions.

(One block shown = 1 mm)